



U.S. Department of Energy  
Energy Efficiency and Renewable Energy

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# A Cost-Benefit Assessment of Gasification-Based Biorefining at U.S. Kraft Pulp Mills

**DOE OBP Thermochemical Platform Review Meeting  
June 7-8, 2005**

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- **Project Background**
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- **Summary**



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- Supports milestone M6.4.1: “Identify economically viable product(s) from syngas (evaluate technologies for mixed alcohols, DME and FTL)”
- Builds on 2003 black liquor gasification combined cycle (BLGCC) assessment
- DOE & industry need objective analysis of the business case for P&P biorefineries, to guide RD&D & commercialization.
- Project is developing detailed mass-energy balances, capital costs, financials and national cost-benefit estimates for pulp & paper biorefineries



# Pathways and Milestones – C-level and Project Milestones

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Aq Residues

Perennial Grasses

Woody Crops

Pulp and Paper

Forest Products

M6.4.1: “Identify  
economically  
viable product(s)  
from syngas...”

Project Milestones	Type	Performance Expectations	Due Date
Draft analytical Results (2 of 4 cases)	D	Detailed mass-energy balances and capital cost estimates and financial analysis	9/2005
Final Report	D	Detailed mass-energy balances, capital cost estimates, financial analysis and full cost-benefit analysis	3/2006



# Technical Feasibility and Risks

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- Project is analytical in nature – no direct technical risks
- Technology development issues are expected to be identified through this analytical work, e.g.,
  - FT economic requirements
  - Key integration issues (e.g., sulfur, lime cycle)
  - Deep sulfur cleaning for product synthesis
- General risks:
  - Bio-refinery represents a significant transformation for the P&P industry
    - Significant new technology adoption affecting core processes (e.g., chemical recovery)
    - New products, markets and partners will be required



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- Project will inform high-level industry decision-makers by providing the greatest level of detail yet on the economic viability of the P&P bio-refinery concept
  - Cost and performance targets needed to be competitive
  - Sensitivity of economic viability to key parameters (e.g., energy prices, capital costs)
  - R&D needs
  - Which products, gasifiers offer best economics and national benefits
- Risks for “Obsolescence”:
  - Interest in bio-refinery may wax and wane with oil prices
  - Alternatives to gasification for BL recovery may continue to improve and therefore provide stiffer competition
  - Significant cost reductions in cellulosic ethanol (via fermentation) could also undermine the viability of the P&P bio-refinery based on the TC platform.



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- Princeton University (Eric Larson)
  - Project lead
  - Capital cost estimating, mass-energy balances, overall integration
- Navigant Consulting (Ryan Katofsky)
  - Cost-benefit modeling, financial analysis, energy and environmental benefits
- Politecnico di Milano (Stefano Consonni)
  - Detailed mass-energy balances/system modeling
- Institute for Paper Science and Technology (Georgia Tech) (Jim Frederick, Kristiina Iisa)
  - Pulp mill integration issues
- Key Activities
  - Select four process configurations for detailed evaluation
  - Develop detailed mass-energy balances, including integration with P&P processes
  - Develop capital cost estimates
  - Conduct detailed financial analysis and cost-benefit analysis
  - Identify R&D needs and next steps



# History and Accomplishments

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### Meetings to date

- Kickoff meeting held Princeton (Jan-05)
- First Steering Committee meeting held in DC (Mar-05)
- Second Steering Committee meeting held in Chicago (Jun-05)

### Activities to date

- Developed screening criteria and ranked 12 configurations
- Selected 2 of 4 cases for initial evaluation (DME as product)
- Evaluated different pulping options
- Development of detailed mass-energy balances underway
- Cost-benefit model under development



# History and Accomplishments

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## Screening Analysis

- Considered input from the DOE Value Added Products from BL Syngas process
- We ranked two configurations for each of six products.
- Products:
  - FT, DME, methanol, mixed alcohols, bio-ethanol, and H<sub>2</sub>
- Configurations:
  - BL gasification only
  - BL + biomass gasification (“maximum production”)
- Each of the 12 configurations was scored on a 1-4-7-10 scale against each of the criteria
- The focus was not on absolute certainty in the data but on determining the relative rankings of the configurations.

*Criteria and Relative Weights (**bold** denotes category weight)*

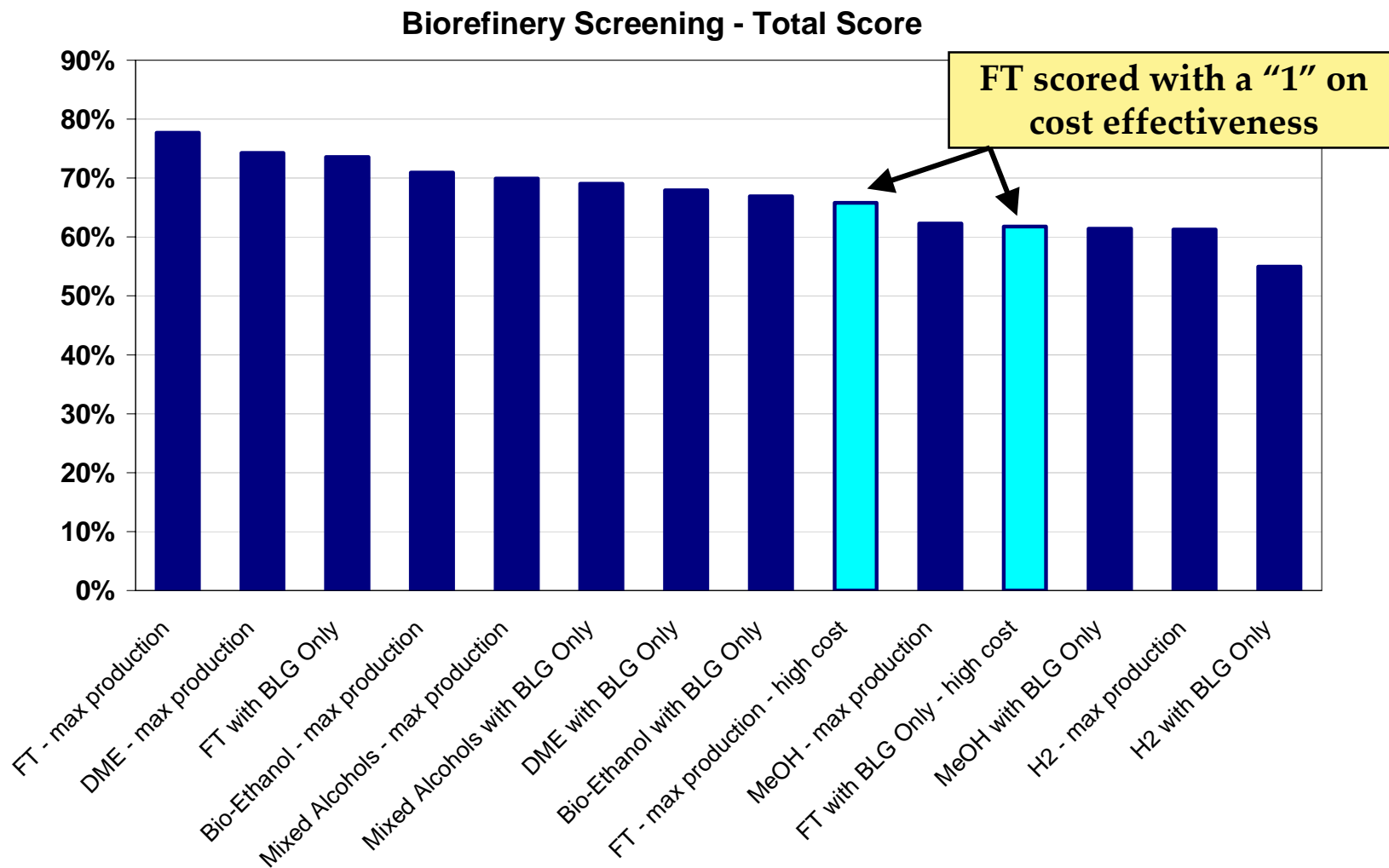
<b>Markets and Economics</b>	<b>47%</b>
Market size of existing product (larger is better)	31%
Institutional partnerships required (business complexity)	8%
Potential for long-term economic competitiveness (incl. high-value co-products, potential for lower costs than alternatives)	42%
Availability of near-term policy supports and regulatory drivers	12%
Potential for new markets	7%
<b>Mill and Infrastructure Integration Issues</b>	<b>30%</b>
Technology status (look at all pieces)	25%
Need for/use of supplemental fossil fuels	5%
Access to necessary infrastructure (transportation, refining, marketing)	15%
Product compatibility with existing infrastructure	18%
Ease of integration with the mill (energy, core process)	27%
Potential for cost-savings at the mill (e.g., O <sub>2</sub> , pulping yields)	10%
<b>Societal Benefits</b>	<b>23%</b>
Reduce or eliminate dependence on foreign oil	46%
Product toxicity/other environmental barriers of product	21%
Expected emissions benefits (lifecycle, including CO <sub>2</sub> )	32%



# History and Accomplishments

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## *Screening Analysis – For use as Transportation Fuel*





# History and Accomplishments

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## *Steering Committee Decisions to Date*

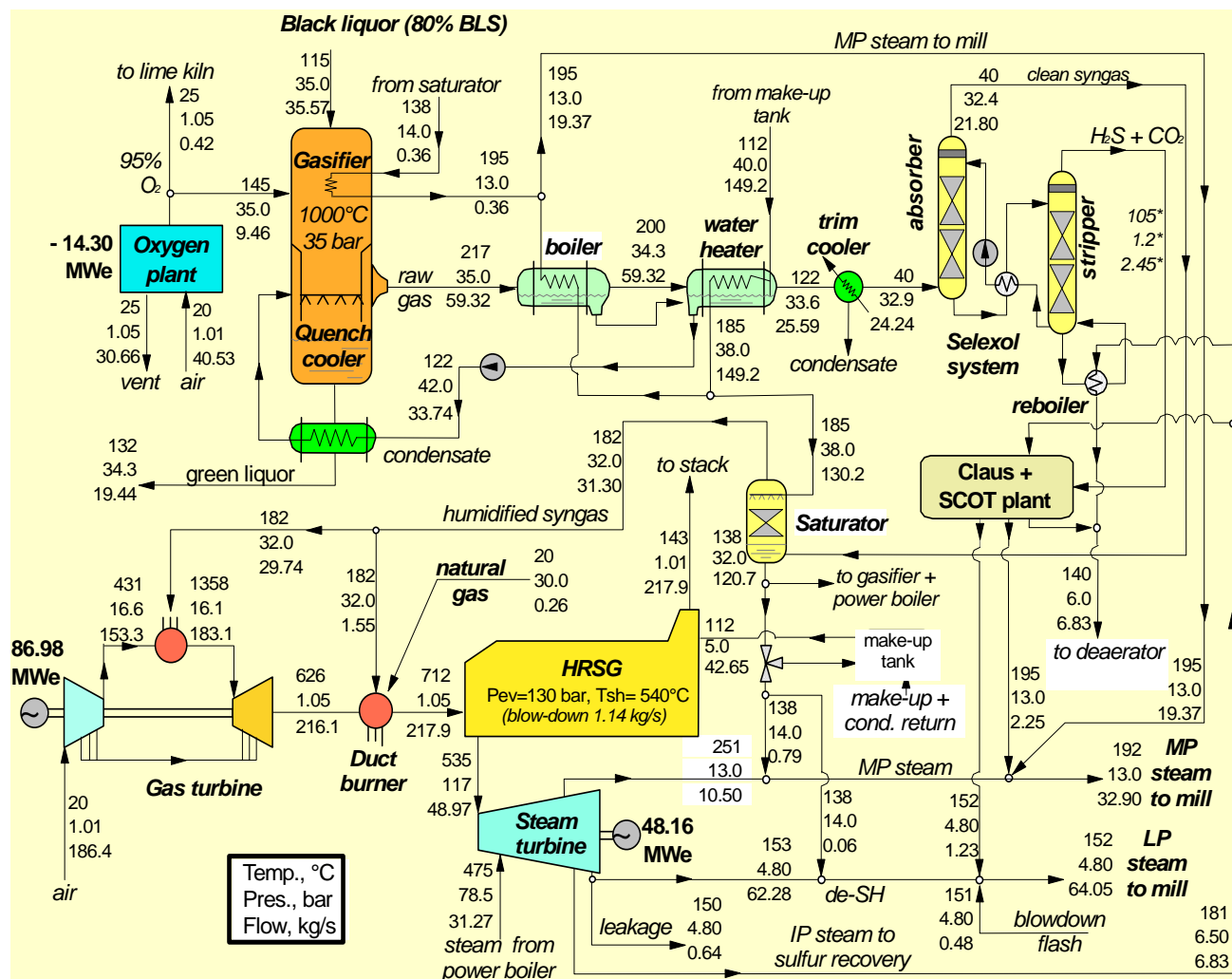
- Detailed cases for design/analysis should be consistent with previous BLGCC study to enable valid comparisons
- Two of four detailed cases decided:
  - Case 1: Maximize DME output from BL syngas. Use residues in boiler and buy electricity. Compare with BLGCC.
  - Case 2: DME with gasification of both BL and purchased residues; buy electricity (if needed). Likely better economics than case 1.
- Designs for final two cases under discussion



# History and Accomplishments

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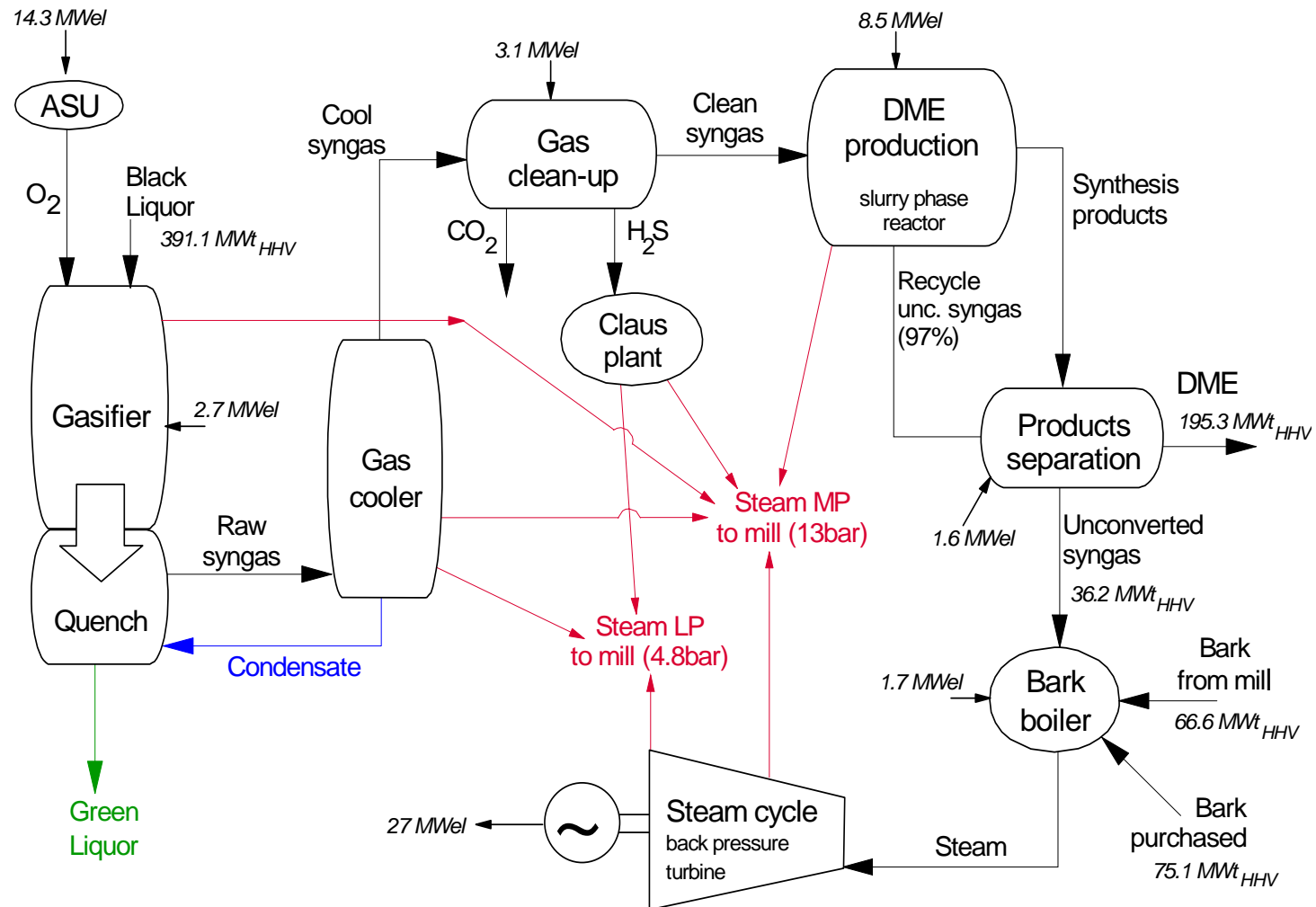
## High-temperature gasifier /small scale GT (from BLGCC Study)



# History and Accomplishments

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*High Temperature BLG (HTBLG) with max DME production:  
overall plant configuration and simulated steam/power balance*

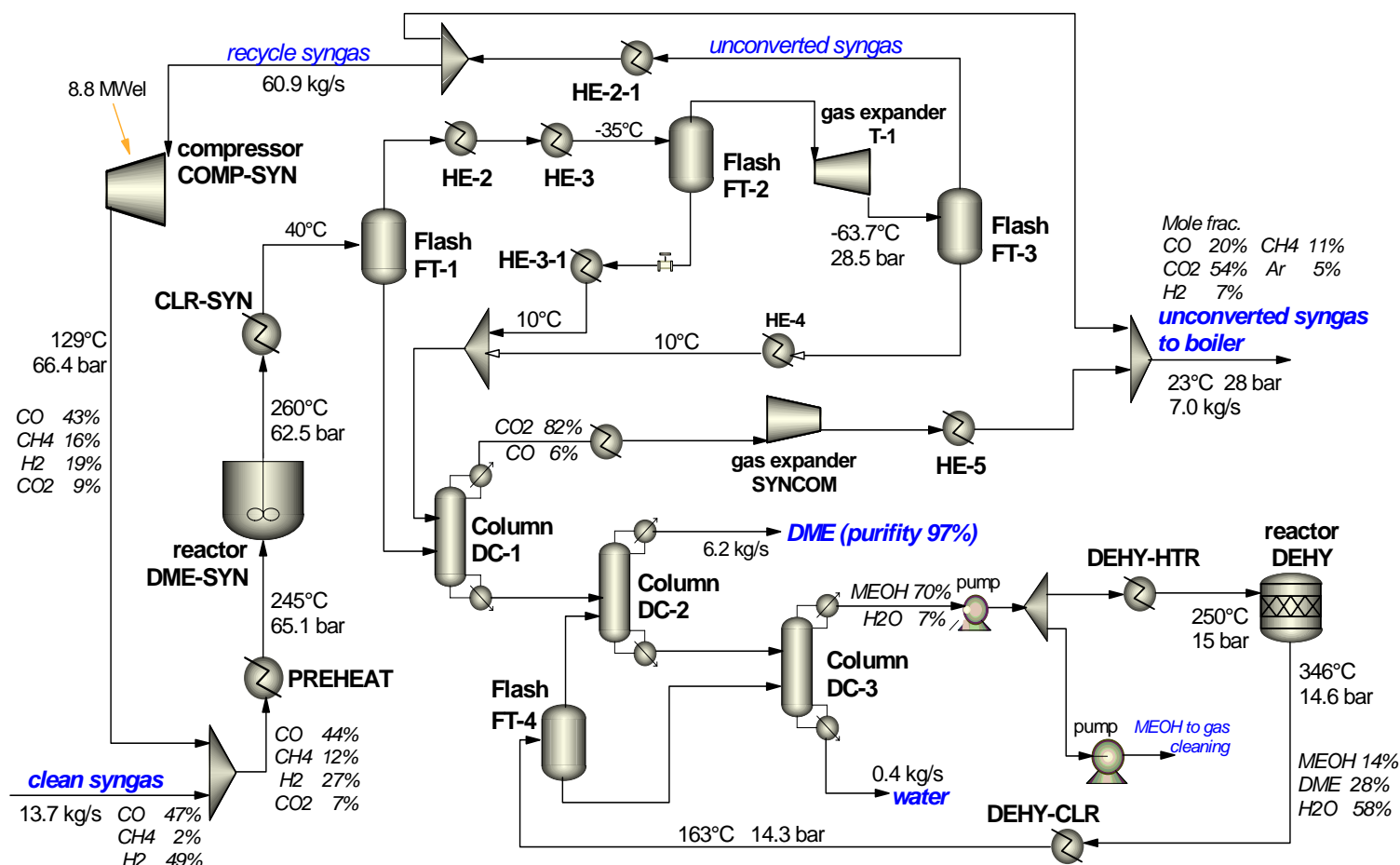




# History and Accomplishments

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## HTBLG with max DME production: Aspen model of Fuel Synthesis Island





# History and Accomplishments

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## *HTBLG-max DME vs Tomlinson: overall performance (1)*

			Tomlinson	HTBLG
FUEL INPUT	Black liquor (DS)	kg/s	31.5	28.5
		MW/t HHV	437.6	391.1
	Total Bark	MW/t HHV	71.2	141.7
	from mill	MW/t HHV	71.2	66.6
	purchased	MW/t HHV	-	75.1
	Lime kiln fuel oil	MW/t HHV	33.1	38.2
CLEAN SYNGAS	Mass flow	kg/s	-	13.7
	Power	MW/t HHV	-	268.7
	H <sub>2</sub> /CO Ratio	mol/mol	-	1.05
FUEL PRODUCTION	Recyrculation flow of unconverted syngas	%	-	0.97
	Unconverted syngas to boiler	kg/s	-	7.0
		MW/t HHV	-	36.2
	DME	kg/s	-	6.2
		MW/t HHV	-	195.3
COOLING DUTY	Cleaning syngas	MWref	-	5.8
	cop		-	1.8
	DME condensation	Mwref	-	1.7
	cop		-	2.2
	DME distillation	MWref	-	2.4
	cop		-	2.8



# History and Accomplishments

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## *HTBLG-max DME vs Tomlinson: overall performances (2)*

			Tomlinson	HTBLG
STEAM TO MILL	MP steam to mill	kg/s	35.2	32.9
		MWt	69.3	64.8
	LP steam to mill	kg/s	67.6	64.1
		MWt	142.8	135.3
POWER	Steam turbine gross output	MW <sub>el</sub>	72.0	28.3
	Syngas expander output	MW <sub>el</sub>	-	2.6
	<i>Total gross production</i>	MW <sub>el</sub>	<i>72.0</i>	<i>30.8</i>
	Aux for steam cycle	MW <sub>el</sub>	6.7	1.3
	Aux for bark boiler	MW <sub>el</sub>	1.0	1.7
	Aux for gasification island	MW <sub>el</sub>	-	2.7
	Compressor clean syngas	MW <sub>el</sub>	-	2.2
	Compressor recycle gas	MW <sub>el</sub>	-	8.8
	ASU	MW <sub>el</sub>	-	14.3
	Refrigeration plant cleaning gas	MW <sub>el</sub>	-	3.1
	Refrigeration plant DME separation	MW <sub>el</sub>	-	1.6
	<i>Total use</i>	MW <sub>el</sub>	<i>7.7</i>	<i>35.7</i>
	<b>Net power production</b>	<b>MW<sub>el</sub></b>	<b>64.3</b>	<b>-4.9</b>
	Mill electricity consumption	MW <sub>el</sub>	100.1	100.1
	<b>Power purchased from grid</b>	<b>MW<sub>el</sub></b>	<b>35.8</b>	<b>105.0</b>



# History and Accomplishments

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## *Summary*

- Model and calculation algorithm of BLGF systems have been established and tested
- Plant configuration for HTBLG with max DME production (Case 1) has been specified and modeled
- Nearly final heat/mass balances for Case 1 are available to start cost assessment
- Results are in good agreement with results of European Altener/Nykomb DME study



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Total Budget: \$747,000 (including \$195,000 cost share)

### Phase I (9/04 – 6/05)

- Project startup
- Literature review
- Selection of detailed cases
- Develop modeling tools

### Phase 2 (6/05 – 3/06)

- Generate draft results
- Interim review meeting
- Revise analysis, write draft final report, and circulate for review
- Final review meeting
- Prepare final report



# Critical Issues and Show-stoppers

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- Analytical tools well developed
- Critical issues:
  - Obtaining sufficient information on developmental technologies to model effectively
  - Capital cost estimating for Nth plant designs
- Project team is getting input from paper industry, UOP, Shell, BP to assist with modeling
- No show-stoppers identified so far or expected.



# Plans and Resources for Next Stage

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- Not applicable



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- Project is on schedule and on budget
- Industry stakeholders are actively engaged
- Earlier work (BLGCC) found good long-term business case for BL gasification, especially if environmental benefits can be internalized in the financials.
- Earlier BLGCC work also found that public benefits were large enough to justify government investment to reduce risk and accelerate commercialization of BL gasification systems.
  - If the biorefinery analysis shows similar or greater benefits, this reinforces the earlier study's conclusion
- There will be a clear need to continue to push for commercialization in the 2010 timeframe due to the window of opportunity presented by the recovery boiler replacement cycle.